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MECHANICAL DESIGN PROBLEMS ASSOCIATED WITH  
TURBOPUMP FLUID FILM BEARINGS

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## INTRODUCTION

Most high speed cryogenic turbopumps for liquid propulsion rocket engines currently use ball or roller contact bearings for rotor support. The operating speeds, loads, clearances, and environments of these pumps combine to make bearing wear a limiting factor on turbopump life. An example is the high-pressure oxygen turbopump (HPOTP) used in the space shuttle main engine (SSME). Although the HPOTP design life is 27,000 seconds at 30,000 rpm, or approximately 50 missions, bearings must currently be replaced after 2 missions [1]. One solution to the bearing wear problem in the HPOTP, as well as in future turbopump designs, is the utilization of fluid film bearings in lieu of continuous contact bearings.

Hydrostatic, hydrodynamic, and damping seal bearings are all replacement candidates for contact bearings in rocket engine high speed turbomachinery. These three types of fluid film bearings have different operating characteristics, but they share a common set of mechanical design opportunities and difficulties. Results of research to define some of the mechanical design issues are given in this report. Problems considered include transient start/stop rub, non-operational rotor support, bearing wear inspection and measurement, and bearing fluid supply route. Emphasis is given to the HPOTP preburner pump (PBP) bearing, but the results are pertinent to high-speed cryogenic turbomachinery in general.

## START/STOP RUB

The basic concept of fluid film lubrication is that the fluid film pressure prevents journal contact with the bearing. In rocket engine turbopumps, the pumped fluid is also the lubricant. At pump start up there is insufficient pressure to lift the rotor and an initial rub occurs between the rotor and bearing. The rub continues until fluid flow is sufficient for the lubricating film to form. The rub causes bearing and rotor wear, creates the danger of fire and explosion in liquid oxygen (LOX) pumps, and produces an initial backward rotor whirl.

The rub problem could be eliminated by the use of a secondary pressure source to float the rotor prior to initial rotation or by insertion of a contact bearing in parallel or series with the fluid film bearing. A secondary pressure source would require piping, valves and controls leading to an unacceptable increase in system weight and complexity. A hybrid contact-fluid bearing is more complex and has a larger space requirement than fluid bearings, and could still be a limiting factor in higher speed future generation pumps.

Fluid film bearing designs that withstand the start-stop rub problems have been available since at least 1969 [2]. A primary consideration is the appropriate bearing material for the particular cryogen. Materials testing and development is being conducted by several contractors and

agencies, but wear-related data is still relatively unavailable to the designer.

No transient start-stop rotordynamic model is available to provide the designer with quantitative or qualitative information on the number, duration and severity of rubs, what wear might occur, when rotor lift develops, or the general bearing presteady-state dynamic behavior prior to actual construction and testing of a prototype pump. This is likely due to the difficulties of developing an analytical dynamic model. The start-stop transient bearing supply pressure creates a time-variable bearing flow rate and stiffness that is perhaps also nonlinear. It is not known whether a dry friction, viscous friction, smearing or abrable rub model best represents the physics of actual rubs. Yet the rub model selected will affect the system model behavior [3]. The rotor speed and applied load transients depend upon which engine system is using the pump. In the case of hydrostatic bearings, there is likely a combined hydrostatic/hydrodynamic effect. A rigid rotor model could be sufficient for design purposes, but a flexible shaft model might provide more realistic results.

#### NONOPERATIONAL ROTOR SUPPORT

Fluid pressure is not available to support the rotor when the pump is nonoperational during descent from orbit, landing, ferrying and ground handling. In static equilibrium the rotor rests on the bearing surface, but due to bearing clearance is free to rattle within the bearing as the pump is moved. The magnitude of the stresses generated by motion-induced impacts between the rotor and bearing depend upon the magnitude and frequency of the the loads, the dimensions and material properties of both the rotor and bearing, and the bearing clearance. Surface damage to the bearing land and rotor surfaces could reduce bearing efficiency and rotor fatigue life.

#### WEAR DETECTION

Post-operational wear detection methods, without pump removal from the engine, need to be developed for fluid film bearings. Bearing wear due to rubs is not axially or circumferentially uniform. The required measurement sensitivity depends upon the amount of bearing wear permissible before performance degrades, which is probably a fraction of the few thousandths of an inch bearing clearance.

Static load-deflection methods which correlate changes in bearing stiffness with wear, similar to that used for HPOTP ball bearings, is a possible measurement technique. Signature analysis on data recorded either during or after operation could provide wear information.

#### FLUID SUPPLY ROUTE

The fluid supply route must be from a high pressure source to a low pressure sink. Details of the route depend upon the bearing type and pressure requirements, as well as the location of available sources and sinks. Flow is directly through a hydrodynamic journal bearing, whereas hydrostatic bearings are fed either externally through the bearing or internally through the rotor. In the case of the HPOTP pump end (PE) bearing, for either a journal or externally fed bearing design, the likely source is the preburner impeller outlet (approx. 7000 psi) with the sink at the main pump inlet (approx. 300 psi). Sufficient flow probably does not exist for an internally fed HPOTP PE bearing since turbine end coolant is drawn through the rotor cavity.

Fluid filtration must be provided in the coolant path to remove solid particles that could cause bearing damage by being trapped in the small clearances. Projected clearances for the HPOTP PE bearing are in the range of 0.0002 in to 0.0008 in whereas the maximum LOX particle size permitted for the SSME is approximately 0.032 in.

#### REFERENCES

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